Do Neural Networks Dream of Gravitational Lensing?

Other

Josh Wilde
Supervisors: Prof. Stephen Serjeant and Dr. Jane Bromley

The Open University

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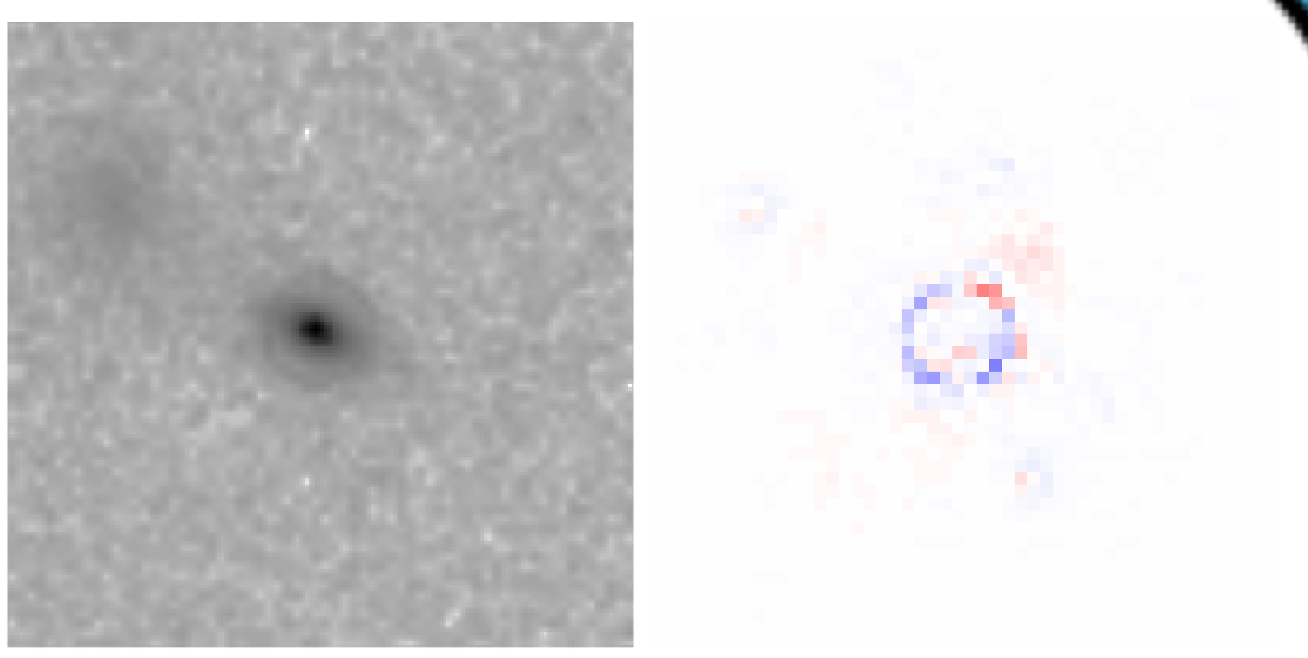
In the near future Euclid Space Telescope Launch. Euclid is expected to 100,000 gravitational lenses from over a billion objects during the course of its mission. This is too much data for humans to go through by eye. We need to develop an approach to find gravitational lenses from this dataset. Which can allow us to constrain values such as the dark matter equation of state and provide a good measurement of cosmological geometry.

Gravitational Lenses

Gravitational Lenses occur when a typically red elliptical galaxy has enough mass to bend the space around it. This distorts the typically blue background galaxies. The effects can be seen here, as the blue galaxy bends around the central galaxy. Gravitational lensing allows us to measure the dark matter halo around the central galaxy and if a variable source is lensed we can get an independent measurement of H0. The value of the current speed of the expansion of the universe (H0) is particularly important as uncertainty in its value is the current issue at the heart of The Crisis in Cosmology.

Occlusion Maps

One method to understand how the CNN classifies images is to place a 4x4 pixel black square over a potion of the image and record the prediction from the CNN for that image. The black square is moved and this process is repeated. The change in prediction is shown on the right. The features the CNN associates with lensing can be seen in blue & the features associated with non-lensing can be seen in red. The CNN highlights the Einstein ring in blue indicating that the CNN associates Einstein rings with gravitational lensing.



Non-lens Feature   Lens Feature

Deep Dream

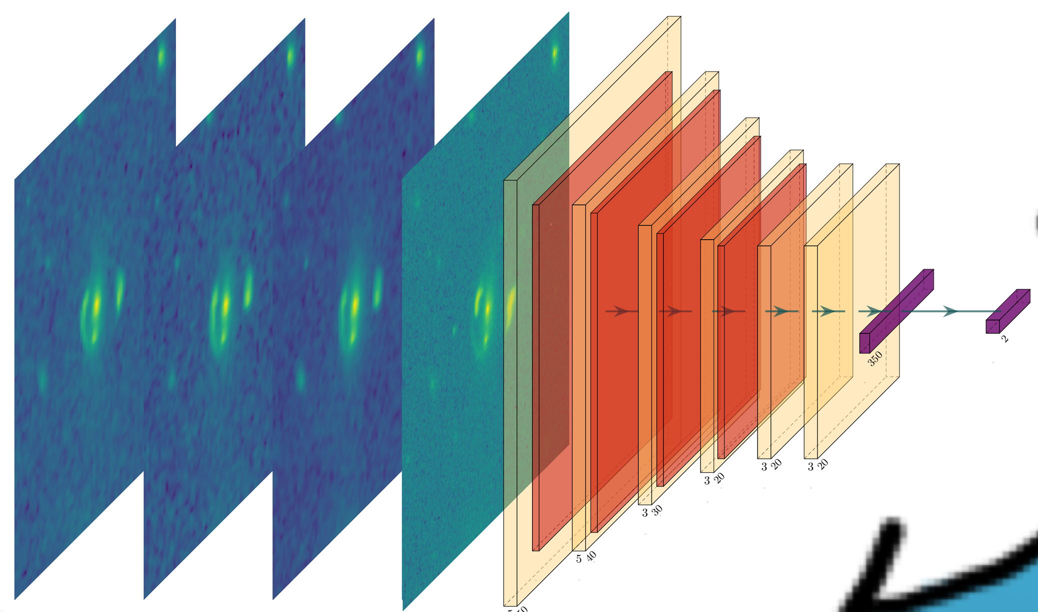
Another method to understand how the CNN classifies images is a method called Deep Dream. Instead of using an image as input to the CNN to get a prediction as an output. We flip the CNN and decide the output we want from the CNN, then we 'train' the CNN to achieve this value but instead of updating the weights inside the CNN, we update the input image. This changes the input image to highly activate the CNN for a given value. We can use this to infer what features in the image the CNN associates with lensing & non-lensing. The Original image is in the centre, the image to the left activates non-lens, and the image to the right activates lens. The non-lens image makes the Einstein ring redder, whilst the lens image makes the Einstein ring bluer.

Machine Learning

Machine Learning is a technique which has become very popular in astronomy in recent years. This work makes use of Convolutional Neural Networks (CNNs) this is the same technology used for facial recognition, virtual backgrounds, and social media filters. CNNs are based on how the eye and neurons process data.

This CNN takes 4 colour channels as input (H, J, Y, VIS). There are three datasets for training a CNN, training set (45,000 images), validation set (3,000 images) , and test set (12,000 images). For training, the CNN is given the image and its true class. The weights inside the CNN are updated. This will increase the CNN's accuracy on the training data. Once the CNN has seen all the training data at the end of an epoch, the CNN is applied to the validation data. The weights are not updated during this process. The accuracy of these two datasets are compared, to ensure that the CNN can still generalise to unseen data. Once these accuracies diverge significantly the network is overfitting and is just memorising the training data. The CNN weights are saved at the epoch where the CNN generalises the best to the validation data. The test set is then applied to the CNN to test the CNN's performance on completely unseen data .

The CNN computes a value between 0 and 1 for each image with a threshold at 0.5, 0 being a non-lens, and 1 being a lens. This CNN has a precision of 0.473, a recall of 0.869, and an accuracy of 57.3%.



Compound Lenses

When two gravitational lenses align, they form multiple lensing planes creating multiple Einstein rings, these are called compound lenses. I created 20,000 compound lens images using the SkyPy & Lenstronomy python packages, 10,000 of these are compound arcs & 10,000 are double Einstein rings. The CNN has never seen compound lenses before, these images were created to find out if the CNN can identify compound lenses as gravitational lenses. The reason for this is that since compound lenses are rare we want to make sure we are not actively selecting against them when searching for gravitational lenses. Compound lensing can be used to calculate the dark matter equation of state to within 10%. This CNN achieves a completeness of 76% for compound arcs and 34% for double rings.

The CNN is applied to real data from the Hubble Space Telescope and Hyper Suprime Cam. These images are both classified as gravitational lenses by the CNN.